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Impact of Tillage Depths and Different Types of Phosphorus Fertilizers on Broad Bean Production

Qusay Sameer Sabah[1], Marwan Noori Ramadhan[1], Ali Hussein Awad[1]

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ABSTRACT

Background: Tillage depth and fertilizer type are critical factors affecting broad bean production. Conventional fertilizers provide essential nutrients, but recent developments in nanofertilizers can offer potential benefits such as improved nutrient efficiency and reduced environmental impact.

Methods: A field experiment was conducted in Al-Qurna District, north of Basrah Governorate, during the 2022-2023 winter growing season to study the effects of three tillage depths (10, 20 and 30 cm) and three types of fertilizer treatments (F0 without fertilizer, F1 triple superphosphate (21% P) fertilizer at a rate of 60 kg P/ha applied in a single dose before planting and F2 nanophosphorus fertilizer at 1.5 liters/experimental unit at a rate of 3 g/L applied in two doses at stem elongation (3 clearly extended nodes, BBCH code 33) and fruit development (50% of pods reached final length, BBCH code 75) on yield components and yield of broad bean. A randomized complete block design with three replicates was used to carry out the experiment in accordance with the split plot arrangement. Tillage depths were located in the main plots and fertilizers of various types were located in the subplots.

Result: The results showed that different tillage depths had a significant effect, as the depth of 30 cm recorded a significant superiority in plant height 39.89 cm, number of seeds per square meter 103.44 seeds/m^2, pod fresh weight 427.33 g/m^2 and biological yield 1302.78 g/m^2. The fertilizer type F2 was superior in plant height 42.44 cm, number of seeds per square meter of 104.67 seeds/m^2, weight of 100 seeds 247.56 g, pod fresh weight of 432.00 g/m^2 and biological yield of 1183.89 g/m^2. The interaction also had a significant effect on most of the studied traits.

Key words: Bulk density, Fresh pod weight, Moldboard plow, Nano-phosphorus fertilizer, Number of seeds per square meter.

INTRODUCTION

Broad beans (*Vicia faba* L.) are among the most important seeded legume crops. Rich in protein and are a staple food in many countries (Arya *et al*., 2024; Devi *et al*., 2025). They are also used as animal fodder (Santiago *et al*., 2023). By fixing atmospheric nitrogen through bacterial nodules that grow on the roots, broad beans improve soil sustainability (Cao *et al*., 2017; Fogelberg *et al*., 2023). Additionally, legumes are used as cover crops to prevent soil erosion (Ghorbi *et al*., 2024). They also provide nitrogen for subsequent crops (Mesfin *et al*., 2023). Soils constantly lose nitrogen through denitrification, irrigation, rainwater leaching and absorption. By assistant of rhizobia bacteria, which commonly live alongside legumes, legume crops play a vital role in improving soil fertility (Sharma *et al*., 2023).

Both soil moisture content and compaction are affected by varying tillage depths. According to previous studies, deep tillage often improves soil moisture retention and reduces bulk density (Sinkevičienė *et al*., 2024). Bulk density is frequently used to study soil physical properties and evaluate various agricultural practices (Ramadhan and Alfaris, 2023). Bulk density can be considered a key measure for describing soil structure, as it indicates soil compaction in relation to its volume and porosity (Hernanz *et al*., 2000; Nassir *et al*., 2024).

Furthermore, tillage depth affects nutrient distribution in the soil, which in turn impacts plant growth. Crop performance can be improved by increasing tillage depth, thereby enhancing soil structure and facilitating nutrient uptake (Naeem *et al*., 2020). For nitrogen-fixing legumes, phosphorus is an essential mineral that directly affects plant growth (Ramadhan, 2024). Adequate phosphorus is essential for many aspects of plant physiology, including photosynthesis, nitrogen fixation, flowering, grain production and ripening (Attar *et al*., 2012; Gerenfes and Negasa, 2021; Khare *et al*., 2025). Additionally, phosphorus promotes root formation, particularly fibrous and lateral roots (Panigrahi *et al*., 2024). It also plays a crucial structural role in nucleotides, phospholipids, coenzymes and nucleic acids (Kolodiazhnyi, 2021; Anjum *et al*., 2024).

[1]Department of Agricultural Machines and Equipment, College of Agriculture, University of Basrah, 61001, Iraq.

Corresponding Author: Marwan Noori Ramadhan, Department of Agricultural Machines and Equipment, College of Agriculture, University of Basrah, 61001, Iraq.
Email: marwan.ramadhan@uobasrah.edu.iq

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Nanotechnology has the potential to reduce environmental protection costs and improve nutrient utilization (Kale *et al*., 2024; Awad *et al*., 2026). Nanofertilizers are promising alternatives to conventional fertilizers for systematic nutrient delivery (Mohamed and Awad, 2024). However, the effectiveness of phosphorus fertilizer sources may vary depending on soil management techniques.

Despite the recognized key role of phosphorus, systematic field studies investigating the combined effects of phosphorus fertilizer sources and tillage depth remain limited. In particular, the interaction between different forms of phosphorus, including the absence of phosphorus fertilization in low-fertility soils and tillage depth has not been adequately studied. Therefore, this study aimed to evaluate the effect of phosphorus fertilizer sources and tillage depth on broad bean growth and yield.

MATERIALS AND METHODS

Experimental details

In Al-Qurna District, north of Basrah Governorate, a field research was carried out in the winter agricultural season of 2022-2023. Three tillage depths (10, 20 and 30 cm) were used in the experiment with a moldboard plow and three types of fertilizer treatments (F0 without fertilizer, F1 triple superphosphate fertilizer (21% P) at a rate of 60 kg P/ha added in a single batch before planting and F2 nano-phosphorus fertilizer at 1.5 liters per experimental unit at a rate of 3 g/L added in two batches at stem elongation [3 clearly extended nodes, code 33 according to the BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemical industry) scale] and at fruit development (50% of pods reached final length, code 75 according to the BBCH scale). The experiment was implemented according to the split-plot system in a randomized complete block design (RCBD) with three replicates.

The field was leveled and partitioned into test plots after being plowed in accordance with the experiment's tillage depths. There were six lines in each experimental unit, each measuring three meters in length, fifty centimeters between lines (9 m^2) and twenty-five centimeters between plants. The experimental units were separated from each other by a distance of (60 cm) and between each block, there was a distance of (1 meter).

The local fava bean variety was planted on November 26, 2022, with three seeds placed in each hole. A 20-liter sprayer was used to apply the nano-fertilizer. Early in the morning, the spraying procedure was carried out as a foliar spray to the plants. As required, plant and soil service activities were carried out. Only one plant was left in each hole. During the growth season, hand-weeded was done twice and given irrigation as necessary. The harvest extended until March 2023. Random soil samples were taken from different areas of the field (0-30 cm deep) before planting to determine some physical and chemical properties according to standard laboratory procedures (Table 1).

Statistical analysis

The normality test was assessed before statistical tests to verify the fit of the data to a normal distribution. A two-way analysis of variance (ANOVA) procedure, for both plant traits and soil bulk density, was conducted by means of GenStat 12th edition to discover the significance of the factors. The LSD (Least Significant Difference) test with a probability of 5% level was adopted to separate the mean differences. The data were presented as mean values ± standard deviation. The optimal tillage depth and type of phosphorus fertilizer for broad bean production were determined through a comprehensive analysis using the TOPSIS entropy weight method using Microsoft Excel. This approach was applied to assess the combined effects of treatment interactions, which enables the evaluation of the relative impact of treatments, as well as the objective ranking by considering both soil and plant variables simultaneously and reduces subjective bias in comparisons. Using a typical weighted decision matrix that takes into account the values of the indicators under examination, we can assesses decisions by determining optimal and non-optimal solutions. The Euclidean distance between each alternative plan and the optimal and non-optimal solutions is calculated to measure how closely each plan aligns with the optimal solution using the generated weighting model. Ultimately, the plan closest to the optimal solution is selected as the preferred decision when it demonstrates the greatest conformity to the optimality criteria.

Table 1: Some physical and chemical properties of the experimental soil.

Soil properties	Unit	Value	Range
Organic matter	g/kg	1.7	Low
Available N	mg/kg	17.3	Low
Available P	mg/kg	5.7	Low
Available K	mg/kg	105.7	Medium
EC	dS/m	8.9	
pH		7.2	
Sand	%	9.2	
Silt	%	46.6	
Clay	%	44.2	
Texture		Silty clay	
$CaCO_3$	g/kg	254.23	High
K^+	mmol/L	0.57	Low
Na^{2+}	mmol/L	10.12	High
Ca^{2+}	mmol/L	14.81	High
Mg^{2+}	mmol/L	8.43	Medium
SO_4^{2-}	mmol/L	11.84	High
HCO_3^-	mmol/L	5.12	Medium
Cl^-	mmol/L	12.29	High

The following traits were measured

Number of seeds/m²: Calculated from the pods collected from one square meter.

Weight of 100 seeds g: 100 seeds were randomly selected from the seeds collected from one square meter and weighed using a sensitive electric balance.

Fresh pod weight/m²: Estimated from the weight of the pods collected from one square meter.

Plant height cm: Measured from the base of the plant to its top at full maturity.

Biological yield kg/m²: Estimated from the weight of the plants in the two mid-rows, then converted to kg/m².

Soil bulk density g/cm³

The effect of tillage depth on bulk density was evaluated using an analysis of variance, with tillage depth as the main effect. Soil samples were taken after tillage and before harvest for bulk density measurement using stainless steel rings at depths of 10, 20 and 30 cm for each tillage depth treatment. The average bulk density values for the previous three sampling depths were then calculated to represent the bulk density for each tillage depth treatment. Using the oven-dry technique outlined in (Blake and Hartge, 1986), the bulk density of the soil was ascertained. Every analytical procedure was carried out in the labs of the College of Agriculture.

RESULTS AND DISCUSSION

Plant height

Plant height rose as tillage depth increased, as shown in Table 2. The highest plants were found at a depth of 30 cm, while the lowest plants were found at a depth of 10 cm. This is an indication of improvement roots expantion and deepening more easily and absorbing more nutrients.

Regarding the fertilization treatments, Table 2 demonstrates a notable impact on plant height, with the F2 treatment producing a taller plants as compared to the F0 control treatment, which achieved a shorter plants. Because of their greater surface area and improved solubility, nano-phosphorus fertilizers enable plants to absorb nutrients more effectively. Furthermore, applying nano-phosphorus fertilizers in two batches may offer a steady supply of phosphorus during important growth phases. Additionally, compared to conventional fertilizers, nano-fertilizers are less prone to leaching and runoff, which may increase phosphorus uptake, improve photosynthesis and increase plant height.

Significant variations between the combinations of treatments are also evident in Table 2 data. Outperforming the other interactions, the 20:F2 interaction treatment produced taller plants. The 10:F0 and 20:F0 interaction treatments produced the lowest mean for the trait, respectively.

Number of seeds per square meter

The findings demonstrate notable variations in the quantity of seeds per square meter across depths of tillage (Table 3). Outperforming the other depths, the 30 cm depth produced 77.67% more seeds in competition to what the depth of 10 cm produced. Greater soil loosening, enhancing root growth and nutrient uptake could be the reasons for the deeper depth's superiority.

The number of seeds per square meter was considerably impacted by the fertilization treatment, as Table 3 demonstrates. The treatments F2 and F1 produced higher pods per square meter, whereas no-fertilization treatment F0 produced the lowest one. In plants, phosphorus is a necessary

Table 2: Effect of tillage depth and fertilization treatment on plant height.

	Fertilization			
Tillage depth	F0	F1	F2	Mean
10	27.33±3.71	32.66±3.92	37.33±6.35	32.44±2.80
20	27.66±1.76	35.33±2.02	48.00±5.03	37.00±3.39
30	34.66±1.45	43.00±4.00	42.00±1.00	39.88±1.82
Mean	29.88±1.73	37.00±2.31	42.44±2.81	
	Depths	Fertilizers	Depths.Fertilizers	
l.s.d.	5.134*	3.807**	6.577*	

Table 3: Effect of tillage depth and fertilizer treatment on the number of seeds per square meter.

	Fertilization			
Tillage depth	F0	F1	F2	Mean
10	36.33±8.83	71.00±14.57	67.33±5.78	58.22±7.56
20	40.00±6.42	73.00±15.50	128.33±9.59	80.44±14.04
30	63.33±9.38	128.66±14.90	118.33±13.34	103.44±11.97
Mean	46.55±5.93	90.88±12.06	104.66±10.70	
	Depths	Fertilizers	Depths.Fertilizers	
l.s.d.	30.25*	19.76**	36.12*	

component for photosynthesis and energy transfer. When enough phosphorus is supplied throughout crucial growth stages, photosynthetic efficiency is improved, which promotes seed formation and increases the quantity of seeds. Aziz and Zrar, (2021) discovered that in Silty Clay Loam soil, applying nano-NPK fertilizer once and twice enhanced grain yield per plant compared to not applying any at all.

Tillage depth and fertilizer treatments were found to interact significantly; the 30:F1, 20:F2 and 30:F2 treatments produced the greatest averages of pods per square meter, while the 10:F0 treatment produced the lowest one.

Weight of 100 seeds

The findings of the analysis of data demonstrate that tillage depth had a substantial impact on the weight of 100 seeds; depths of 20 and 30 cm produced the greatest percentage of increase of 19.73 and 10.22% compared with a tillage depth of 10 cm (Table 4). Soil loosening, improved nutrient uptake, greater photosynthetic products stored in the grain and easier root penetration and better proliferation could all contribute to the weight rise.

Fertilizer treatments enhanced the weight of 100 seeds, as Table 4 demonstrated. The F2 treatment produced 40.68% increase in weight of 100 seeds compared to the F0 treatment. Fertilizers containing nano-phosphorus can encourage stronger root development, which enhances the plant's capacity to take up both nutrients and moisture from the soil. Improved seed weight may results from healthier roots due to better absorb and distribute of nutrients. In sandy soil, (El-Azizy and Habib, 2021) discovered that using nano-fertilizers including potassium and phosphorus increased the weight of 100 seeds when compared to not spraying.

The data also revealed significant variations between the interaction treatments. The 20:F2 interaction treatment achieved the maximum weight, while the 10:F0 interaction treatment achieved the lowest one, with an increase of 93.40%.

Fresh weight of pods

The analyzing of measuring data demonstrates that fresh pod weight increased significantly when tillage depth was increased (Table 5). The maximum percentage increases of 46.54% and 31.07% were obtained at depths of 30 and 20 cm, compared to those recorded at depths of 10 cm. Plant growth improves with the ability of tillage to properly loosen the soil, promote root growth and enhance nutrient uptake, which provide the requirements for photosynthesis, which is reflected in the increased weight of the pods. These findings are corroborated by the statement that deep tillage increases the total yield of common beans on sandy clay loam soils whereas shallow tillage decreases it (Lavrenko *et al*., 2021).

Fertilizer type has a considerable impact on fresh pod weight, as demonstrated by Table 5 statistical analysis of variance. Interestingly, the F2 treatment increased the fresh pod weight by 59.47%, when compared to the F0 (no fertilizer) treatment that produced the lowest fresh pod weight. Phosphorus is made available to plants in greater amounts and for longer periods of time using nano-fertilizers, which improve pod growth and increase their weight via limiting nutrient loss from runoff or leaching.

Significant evidence of interaction between fertilizer application and depth of soil manipulating was found in the investigated data. In comparison to the 10:F0 and 20:F0 treatments, the combined levels of 30:F2 increased pod weight by 127.88% and 100.41%, respectively.

Table 4: Effect of tillage depth and fertilizer treatment on 100 g seed weight.

	Fertilization			
Tillage depth	F0	F1	F2	Mean
10	141.33±15.37	208.00±4.00	237.33±15.71	195.55±15.59
20	184.00±18.03	245.33±8.11	273.33±3.52	234.22±14.40
30	202.66±15.37	212.00±18.33	232.00±12.00	215.55±8.85
Mean	176.00±12.20	221.77±8.35	247.55±8.70	
	Depths	Fertilizers	Depths.Fertilizers	
l.s.d.	28.27*	19.44**	34.69*	

Table 5: Effect of tillage depth and fertilization treatment on fresh pod weight (g/m^2).

	Fertilization			
Tillage depth	F0	F1	F2	Mean
10	214.00±74.83	323.33±56.52	337.33±70.79	291.55±39.12
20	243.33±58.37	432.33±68.98	471.00±47.72	382.22±45.90
30	355.33±28.91	439.00±27.87	487.66±33.41	427.33±24.51
Mean	270.88±35.83	398.22±32.84	432.00±35.58	
	Depths	Fertilizers	Depths.Fertilizers	
l.s.d.	85.62*	26.59**	84.39*	

Biological yield

Analysis of the variance of this trait showed that the depth of tilled soil significantly affects plant biomass productivity. As shown in Table 6, plant biomass productivity increased by 116.66% when tilled to a depth of 30 cm compared to a tilled depth of no more than 10 cm. This trend aligns with the suggestion that deeper roots and more spread, improves nutrient uptake, which improves branching, leaf area and, consequently, biological yield.

Fertilization treatments also significantly affected the biological yield. Treatments F2 and F1 outperformed, yielding the highest percentage of 70.94 and 47.29%, respectively, compared to treatment F0. Phosphorus is an essential element to perform photosynthesis and transmit energy. A sufficient supply of phosphorus during stem elongation and pod formation enhances the effectiveness of storing energy and how plants carry out photosynthesis, contributing to increased biological yield. In general, the superiority of nanophosphorus fertilizer is due to overcoming the negative effects of calcareous and saline soils; instead of the traditional loss of phosphorus through fixation with calcium carbonate or the effect of salinity, the nano-fertilizer particles enter directly through the plant.

A significant interaction was found between the tillage depths and fertilization treatments, as the 30:F2 interaction attained the top biological yield, while the 10:F0 interaction treatment gave the lowest average, with the increase in biomass reaching 262.85%.

Bulk density

Due to soil disturbance, tillage practices have an impact on soil structure. Generally speaking, depending on the kind of tillage procedures used, soil bulk density might indicate soil compaction to differing degrees. With an average depth of 30 cm, Table 7 illustrates how various tillage depths affect bulk density values.

The levels of prior tillage depth treatments have a substantial impact on soil bulk density. The bulk density decreased at 30 cm tillage depth by 6.24 and 7.60% compared to 20 and 10 cm tillage depths, respectively, with no significant differences between them. Deep tillage breaks up compacted layers and reduces the density of manipulated depth by increasing soil porosity. One of the reasons for this decrease is due to the increased friction of loose soil masses with increasing depth and increased fragmentation.

Soil bulk density was also significantly affected by sampling time, reaching its highest value at harvest, compared to after tillage. These results are consistent with those of (Muhsin *et al*., 2021). A reasonable justification for higher density at harvest is to the gradual soil stabilization under irrigation, particle resettlement and wetting-drying cycles (Blanco-Canqui and Ruis, 2018).

TOPSIS evaluation

The TOPSIS entropy weight method was employed to analyze the indicators under study comprehensively. This approach can identify the optimal tillage depth and type of phosphorus fertilizer application. By integrating the data of growth traits and yield, the TOPSIS method provides an efficient way to evaluate several treatments and determine the most effective practices for enhancing broad bean production. According to TOPSIS analysis (Fig 1) the optimum treatment combinations were 30:F2 and 30:F1. These treatments had the highest overall assessment values of 0.909 and 0.907, respectively.

Table 6: Effect of tillage depth and fertilization treatment on the biological yield g/m^2.

	Fertilization			
Tillage depth	F0	F1	F2	Mean
10	407.33±95.50	661.66±32.35	735.00±187.17	601.33±78.93
20	492.66±179.75	1146.00±69.61	1338.66±214.54	992.44±152.69
30	1177.66±122.07	1252.66±57.18	1478.00±169.21	1302.77±77.04
Mean	692.55±139.83	1020.11±95.03	1183.88±148.79	
	Depths	Fertilizers	Depths.Fertilizers	
l.s.d.	521.7*	174.2**	516.9*	

Table 7: Effect of tillage depths and sampling time on soil bulk density g/cm^3.

	Depths			
Time	10	20	30	Mean
After tillage	1.48±0.04	1.47±0.03	1.31±0.01	1.42±0.03
Before harvest	1.53±0.00	1.50±0.04	1.47±0.02	1.50±0.01
Mean	1.51±0.02	1.49±0.02	1.39±0.03	
	Time	Depths	Time.Depths	
l.s.d.	0.0646*	0.0791*	ns	

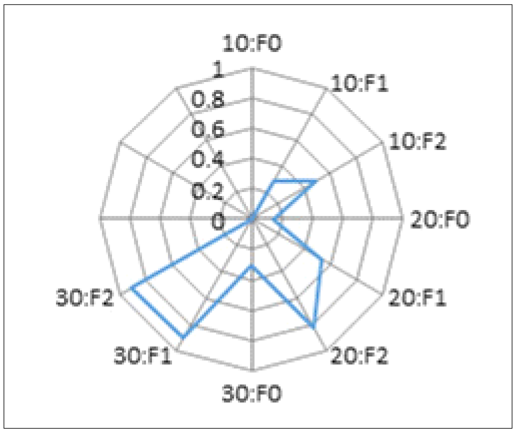

Fig 1: TOPSIS evaluation.

CONCLUSION

We conclude from the experiment results that increasing the tillage depth led to a decrease in the bulk density of the soil at an average depth of 30 cm, which led to an increase in growth indicators and yield components and consequently grain yield. Fertilization treatments also had a significant and varied effect on growth indicators, with the F2 treatment achieving the best values for most growth indicators. Additionally, the 30:F2 interaction treatment produced the greatest average for fresh pod weight and biological yield, in the majority of the characteristics. The TOPSIS model identified 30:F2 as the optimal tillage depth-phosphorus fertilizer type treatment.

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Conflict of interest

The authors confirm that there is no potential conflict of interest related to the publication of the article.

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